ON THE APPLICATION TO INDIVIDUAL SCHOOL CHILDREN OF THE MEAN VALUES DERIVED FROM ANTHROPOLOGICAL MEASUREMENTS BY THE GENERALIZING METHOD.

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I.

The method employed by Quetelet in his anthropometrical studies of the phenomena of human growth was based on two fundamental propositions, (1) the mean of a great number of individuals of the same class is the typus or norm of the class; and (2) the deviations of individuals from the typus follow the law of accidental causes, and are subject to the calculus of probabilities.

From these propositions it results that the typus in any dimension, *e. g.*, height, at any age in the period of growth, is the mean of a sufficiently large number of observations of that dimension at the given age, and that the degree with which the observed approaches the true mean can be determined by an application of the principle of least squares.

When the means of any one dimension, for example, height at each age in the period of growth, are compared, the law of growth in that dimension is at once apparent, and may be expressed graphically in a curve whose abscissæ are years, and whose ordinates are centimetres, kilogrammes, or other units of measurement. Not only is the mean at any age thus fixed, but the probability of any given deviation from that mean is fixed as well. Thus the mean height of 2192 St. Louis Public School girls,* aged 8, is 118.36 cm., with a probable error of

* W. Townsend Porter, "The Physical Basis of Precocity and Dullness," *Transactions of the Academy of Science of St. Louis*, Vol. VI, No. 7, March 21, 1893, pp. 161-181. Also "Untersuchungen der Schulkinder in Bezug auf die physischen Grundlagen ihrer geistigen Entwickelung," read before the Berliner Gesellschaft für Anthropologie, Ethnologie, und Urgeschichte, July 15, 1893, and published in Virchow's *Zeitschrift fur Ethnologie.*

0.079 cm., and a probable deviation of 3.7 cm. This being known, it follows that of the 50 per cent of those who exceed the mean

25	per cent	should	fall	between	118.36	cm.	and	122.06	cm.
16.2	"	"	"	"	122.06	"	"	125.76	"
6.7	"	"	"	"	125.76	"	"	129.46	"
1.8	"	"	"	"	129.46	"	"	133.26	"

and 0.3 should exceed 133.26 cm., while the remaining 50 per cent should deviate from the mean in a precisely similar manner, but in an opposite direction.

The method admits of still another application. It is evident that in the series just given 122.06 cm. is the height of a girl who is taller than 75 per cent of the girls of her age, and not so tall as the remaining 25 per cent. Her position is thus definitely fixed with relation to the mean. She is in fact the typus or mean of the 50 per cent who exceed the mean of the whole number. The height of such an individual at any age would equal $M + d$, where M is the mean height of the age, and d the probable deviation. The values of $M + d$ determined for each age in the period of growth are comparable, and reveal the growth of the typus of the 50 per cent who exceed the mean of the whole number at each age. The growth of the typus of the 50 per cent who fall below the mean height can be similarly made plain, and, by continuing the process, the law of growth at any given deviation from the mean can be determined.

The data for these studies can be collected either by the "generalizing" or "individualizing" plan. In the former, a great number of measurements is made but once on individuals of different ages, and the measurements classified according to age. In the latter, the same individuals are measured yearly, or oftener, during their period of growth, and the measurements classified also by age. The generalizing method is rapidly and easily carried out, whereas the individualizing method demands for its execution exceptional opportunities and exceptional patience, requiring not only

that the measurements be made and the records kept through two decades, but that the number of children measured in the early years of this long period be very great, lest death and desertion so thin their ranks that those remaining to the end shall be too few to yield reliable conclusions. Both methods, when applied to the same material, give identical results with regard to means, including those of subdivisions as well as those of the whole number of observations at any age. The individualizing method does more.

The importance of the individualizing method has been much emphasized, for the reason that it can give information without which the laws derived from means cannot, in the present state of knowledge, be applied to individuals. Before this application can be made it is necessary to know the degree of probability that an individual who at a given age stands at a certain deviation from the mean of any dimension will show the same deviation at other ages; for example, the degree of probability that a girl whose height at age 8 is 122.06 cm., and who therefore deviates 3.7 cm., or $+d$ from the mean (118.36 cm.) of her age, will deviate to the same degree ($+d$) from the mean height throughout her growth. In that case the law of growth for the typus at a deviation of $+d$ from the mean is her law of growth. Otherwise she is an exception, and practical regulations deduced from the law for the typus cannot be safely made binding on her. This knowledge, as has just been said, is furnished by the individualizing method, while the generalizing method is of no assistance in this matter.

The application to individuals of the law of growth of the mean is a subject of immediate practical interest. The connection between theory and practical affairs is here unusually short and clear. Were this application possible, the deviations of children from the laws of normal growth could be quickly recognized, and by timely treatment largely overcome, the evil effects of over-study could be watched and intelligently combated, and systems of education, no longer

exacting from all that which should be exacted only from the mean, could be rationally adapted to the special needs of the exceptionally weak and the exceptionally strong. These beneficent reforms, it is at present believed, must await the slow collection of data by the individualizing method. If it is indeed true that the laws of growth determined for the mean cannot be used for the individual until the individualizing method has established the probability of each individual deviation remaining constant throughout the period of growth, then a generation must elapse — so slow is the gathering of data by this method — before the necessary knowledge is in our hands. I hope to show that this long waiting is unnecessary, and that the data collected by the generalizing method may be used, in a way hitherto unrecognized, for the making of standards by which the deviation of an individual from the mean of his age can be seen to be normal or abnormal.

Let the problem be clearly understood. The question is: This boy or girl is above or below the mean height, or weight, etc. of his or her age,— how shall it be known that this deviation is normal or abnormal? There has been hitherto no satisfactory reply to this question. A vague and partial answer is possible after two measurements separated by at least a year's interval. If the deviation is the same, or very nearly the same, at both measurements, the probability is that the child is growing normally. This probability is greater than the general probability that a normal deviation is more likely to occur than an abnormal one, but its numerical value is wholly unknown. If, on the other hand, the two deviations are unequal, the probability is that the greater of them is abnormal, but the numerical value is here also unknown. How definitely the individualizing method could answer this question is difficult of conjecture, in the present lack of data, but certainly no answer whatever could be expected until after two measurements separated by a year's interval,— a year in which the unchecked cause of an abnormal deviation

might inflict irreparable damage on the organism. Such indefinite and fragmentary knowledge can never be the basis of a practical reform. Any solution of this problem which shall gain general acceptance must be easy to understand and easy to apply, and must give the probable degree of abnormality of any observed deviation. These conditions are, I believe, fulfilled by the following method.

According to the theory of probabilities the heights of a thousand individuals of the same class will arrange themselves as follows: —

[Where M = the mean, and d = the probable deviation]

	$+nd$	3
	$+4d$	18
	$+3d$	67
	$+2d$	162
	$+d$	250
M		
	$-d$	250
	$-2d$	162
	$-3d$	67
	$-4d$	18
	$-nd$	3

Let these be divided into seven groups: —

I.	All	individuals	between	$+nd$	and	$3d$	21
II.	"	"	"	$+3d$	"	$2d$	67
III.	"	"	"	$+2d$	"	$+d$	162
IV.	"	"	"	M	"	$+d$	500
V.	"	"	"	$-d$	"	$-2d$	162
VI.	"	"	"	$-2d$	"	$-3d$	67
VII.	"	"	"	$-3d$	"	$-nd$	21

The mean height, weight, girth of chest, etc. of each of these groups at any given age will be the typus of a certain degree of deviation from the mean of the age,—that is to say, the heights, weights, etc. of each group will be symmetrically distributed above and below the mean height, weight, etc. of the group in the manner already illustrated for the entire undivided number of observations, *i. e.*, the entire

thousand. Each group, therefore, will be characterized by a physical development definitely determined by the means of height, weight, and other physical dimensions. These means taken together form the typus or norm of the group. The individual deviations from this norm follow the theory of probability, and the degree of abnormality presented by any individual deviation can be expressed in the terms of this theory. An example will illustrate this: A boy x shows a deviation in height of $+1, 5\, d$ from the mean height of his age; he falls therefore in group III. The boys in this group possess a mean weight of M^1 kilog., with a probable deviation of $+d^1$, that is, boys from d to $2\, d$ taller than the norm of their age should weigh M^1+d^1 kilog. In like manner they should possess a girth of chest of M^2+d^2 centimetres, and a span of arms of M^3+d^3 cm., and so on. If the weight, etc. of the boy x coincide with the means of his group (group III) his physique is normal, the accuracy of this conclusion being proportionate to the number of different measurements on which it is based. If the boy x deviate more than $\pm d$ from the mean in one or more dimensions his development is abnormal, and the degree of abnormality is measured by the amount of his deviation.

The necessity of choosing some one dimension as a basis of such a system of measurement is self-evident. There are good reasons, partly theoretical and partly practical, why height rather than weight should be taken as a basis. Height is more stable, less liable to irrelevant fluctuations than weight. An excess in weight can be reduced; a child whose weight is out of proportion to its height may be brought into proportion by suitable diet and exercise; but height once attained cannot be reduced, nor can the growth in height be easily influenced. Practically, therefore, the physical trainer must be content to bring the weight, girth of chest, strength of squeeze, and other physical dimensions up to the mean development which corresponds to the height of the child. Experience has abundantly shown that the relation of weight

to height is of great importance to health, life insurance companies declining to receive applicants whose weight falls much below the standard weight of their height. For these reasons height should be preferred as the basis of the system.

The question whether any given deviation is normal or abnormal is answered by this system in two ways: in respect of height, by the degree of deviation from the mean or norm of the whole number of observations; in respect of other dimensions, by the degree of deviation of the weight, girth of chest, etc. from the mean weight or girth of chest corresponding to the height of the individual under examination, this normal weight, etc. being determined with sufficient exactness by taking the means and probable deviations of the group in which the height falls. It is evident that all cases included within $M \pm d$ must be termed normal, for the chances are even that any individual measurement in a series will fall within $M \pm d$, and are against its exceeding these limits, being 4.64 against 1 that it will fall at $M \pm 2\,d$.

Strictly speaking, all abnormal deviations in any dimension are probably unhealthful, yet an important difference exists in this respect between abnormal deviations in height and abnormal deviations in weight, girth of chest, etc. as related to height. It cannot be doubted that abnormal height is probably (using the word in its technical sense) a disadvantage. The potential energy of the body is converted into mechanical labor and heat, by far the greater expenditure taking the latter form. In the adult the total expenditure in the form of heat is about 2700 calories in 24 hours (Helmholtz), of which 80.1 per cent escape in radiation, conduction, and evaporation from the skin. Thus the superficies of the body plays a great part in the dissipation of energy. The superficies is greater usually in tall children than in short, a difference of special importance in the young, in whom metabolism is much more active than in the adult. More heat is therefore lost by the abnormally tall than by those of normal height. There is a disadvantage also in the loss by mechan-

ical labor. Greater height entails increased work on the heart and on the skeletal muscles. In short, increased loss of energy goes hand in hand with increase in height. Hence in the tall the necessity of a physical development which shall be so much above the mean as to compensate their greater loss of energy. In growing children not only must there be compensation for the expenditure of energy, but there must be energy stored in the increase of tissue which constitutes growth.

If the greater demands of tall children are balanced by a correspondingly greater income of energy, a normal equilibrium or "health" is preserved. It should be clearly recognized that this equilibrium is unaffected by the absolute height, and is dependent only on the relation between height and the other physical dimensions. Consequently, health is as possible in tall children as in those of normal height, although less probable, for the chances against a compensatory development of weight and other dimensions increase very rapidly with the deviation of the height from the norm. The absolute height of an individual is, therefore, of very secondary interest from a practical point of view, because it is not necessarily a state of ill health, whereas the development of weight, girth of chest, etc. in proportion to height is of supreme interest. The lack of proportion between height and other physical dimensions is itself ill health. The tendency of organisms to adapt ends to means is strong, and an imperfect compensation may suffice for most demands. A heart in which an hypertrophy of the left ventricle has partially compensated an insufficiency of the mitral valve may beat regularly enough for ordinary exertions, and yet fail utterly when its possessor is forced to suddenly ascend a height, or to make any other unusual exertion. So a tall child may have a sufficient income of energy to meet the demands of a wisely regulated life, and sink under the burden of unusual tasks.

It has been shown in the foregoing pages that the means derived from anthropometrical measurements by the generalizing method can be used to determine whether the weight and other physical dimensions of an individual are normal in relation to height, and it has been pointed out that this normal relation constitutes the health of the individual. It follows that the normal amount of labor cannot be exacted without injury from those in whom this normal equilibrium is wanting. These facts must therefore be taken into account in a rational school system, and it should now be made plain how this is to be done.

II.

All systems of education have for their object the largest possible development of individual minds. In large schools the tasks by which this development is promoted are those which secure from the child of mean ability its maximum mental output. In practice they are determined by examinations. Hence the existence in every educational institution of classes or grades based on the mental output of the mean pupil, and related to age only in that the output fixed as the standard of any class is necessarily found more often at a certain age than at other ages. Thus there exists a mean age for each class, the greater number of pupils at any age being found in the same class, while some have advanced beyond, and others, equally old, have not yet come so far as this class.

On an average, those who have advanced beyond the greater number of their age are precocious, that is, possess more than the mean capacity for mental labor, while those who are less advanced are dull, possessing less than the mean capacity. It has been demonstrated that there is a physical basis for precocity and dullness.* When numbers sufficiently large for safe statistical work are employed, it is seen that precocious pupils possess a greater mean weight, height, etc. than the mean pupils, and that the latter are heavier and

* W. Townsend Porter, *loc. cit.*

taller than the dull. The mental output is therefore directly related to the physical condition of the pupils. The mean height, weight, girth of chest, etc. in any grade is the mean physical development corresponding to the mental output of the grade. It follows that those who do not possess this development cannot, without abnormal strain, do the work exacted in this grade. On the other hand, pupils who possess more than the mean physical development of their age should be capable of more than the mean labor. Yet the management of this latter class presents but few difficulties, whereas the former class cannot be too carefully protected.

The consequences of continued overstrain in a growing boy or girl are most unhappy. The curves of growth in height and weight of the mean child are characteristic. The quick rise to age 7 or 8, the slower ascent to age 11 in girls and 13 in boys, the remarkable three years of accelerated development preceding puberty, and, finally, the rapid decrease in the rate of growth as full development approaches express the normal development of the type, and, presumably, the normal development of the individual. Overwork may cause a temporary or a permanent deviation in these curves. It is probable, though not certain, that a temporary loss, consequent on a slight overstrain, may not lower the final outcome of the development, but there can be no doubt as to the result of a prolonged strain. In such a case, the probability is strong that the whole subsequent curve will be turned out of its course. A prolonged strain in a growing child harms for life, and leaves a mark which can never be effaced. The danger is greatest in the periods of quickest development, particularly great in the prepubertal period. It is a sufficient commentary on the evils of the present educational methods that during these very years the indiscriminating routine of a system devised for the average pupil is most inflexibly applied to weak and strong alike.

Overstrain can often be recognized both by subjective and objective symptoms. Subjective symptoms, however, are

frequently obtained with difficulty, especially in pupils who are unusually ambitious, and who over-study from choice. An objective symptom is therefore necessary,— a symptom easily demonstrated and almost never wanting. Such a symptom is the failure to gain weight at the normal rate. A persistent loss of weight in an adult is regarded as a matter of grave concern; the persistent failure of a child to make the normal gain in weight is no less grave. It is not pretended that the failure to gain weight always accompanies overstrain, but it is claimed that the number of exceptions is small, and that frequent weighing is the most practical and, in the whole, the most certain method of detecting the presence of influences that are working injury to the development of the child. The skillful breeder of cattle depends on systematic weighing to inform him whether his efforts to secure well-developed animals are meeting with success, but children are left to grow at hap-hazard.

It is not enough that overstrain should be recognized by the harm it has done. The child should be guarded against the possibility of harm. The anthropometrical system proposed in this article offers a means of doing this. It infallibly discovers those whose physical development is below the standard of their age. It no less certainly indicates the physical development which most often accompanies the power to do the mental work of any grade. It therefore divides the pupils into two bodies, those physically competent and those physically incompetent for a clearly defined degree of mental exertion. When working with great numbers, the infallibility of this system is practically absolute and theoretically almost absolute. When applied to individuals, errors will certainly occur, but the number of errors will, according to the laws of probability, be less than the number of correct conclusions. And these errors cannot influence the great fact that such a system is competent to call attention to the children who shall probably be unable to do the normal work of their age without injury. Each individual case must then be treated on its own merits.

The proposed system of physical examination requires—

I. The collection of sufficiently extensive data by the generalizing method.

II. The determination of the means and the probable deviations of height, weight, girth of chest, strength of squeeze, etc. for each age.

III. The division of the individuals at each age into groups in terms of the probable deviation from the mean height, as illustrated above, and the calculation of the mean and probable deviation of the weight, girth of chest, etc. of each group.

IV. The determination of the mean physical development of the pupils in each class or grade of the school system.

V. The physical examination of each applicant for entrance to any grade.

These data permit the enforcement of the following regulation: No pupil whose physical development deviates more than $\pm d$ from the weight, etc. of the mean pupil of his height in a class which his mental output would otherwise entitle him to enter shall be admitted to that class unless with the approval of a medical expert, if possible a regularly appointed school physician, who shall testify that the pupil's strength shall be equal to the strain.